RFID Reader Antenna with Multi-Linear Polarization Diversity

Patrick Fink, Greg Lin, Phong Ngo, Timothy Kennedy, Danny Rodriguez, Andrew Chu, James Broyan, Donald Schmalholz
NASA JSC Houston, TX

***Abstract*—This paper describes an RFID reader antenna that offers reduced polarization loss compared to that typically associated with reader-tag communications involving arbitrary relative orientation of the reader antenna and the tag.**

Keywords—RFID; reader antenna; microstrip patch antenna, polarization diversity, single-feed patch antenna

I. Introduction

In February 2017 NASA began execution of an experiment on the International Space Station (ISS) entitled "RFID-Enabled Autonomous Logistics Management (REALM-1)". The REALM-1 system comprises 6 readers and 24 antennas distributed through 3 of the ISS element modules. Volume and performance constraints motivate a high performance reader antenna design.

To deal with the arbitrary relative orientations of tags and reader antennas, circularly polarized (CP) antennas are frequently employed on the reader side. Since RFID tags are typically linearly polarized to reduce size and complexity, this practice results in approximately ½ of the power being lost from the reader to tag, and another loss factor of ½ on the backscatter from the tag to the reader. In other approaches, switched RF ports on the reader are used to drive orthogonal linear polarizations for diversity. This approach has the disadvantage that the polarization diversity is typically at the expense of spatial diversity. Moreover, tags aligned diagonally with respect to the reader antenna polarizations still suffer the ½ power loss. The reader antenna presented herein overcomes many of these disadvantages by radiating multi-linear (ML) polarizations induced by a frequency hopping spread spectrum (FHSS) protocol. FHSS is required by regulations in many regions, including the U.S. [1], for protocols such as the EPCglobal Class I Generation 2. This antenna design is a multi-mode patch antenna that also addresses another common limitation of patch antennas: that the bandwidth is strongly dependent upon the patch volume.

II. Antenna with Frequency Hopping Polarization Diversity

A. Conventional Circularly Polarized Single Feed Patch

The single feed, dual-mode patch is a well-known approach for achieving circularly polarized antennas [2, 3]. In this approach, the two modes are associated with resonant frequencies at a fixed spacing relative to a center frequency. At a particular frequency, the imparted phase difference associated with the excitation is the 90 degrees required for circular polarization. This design is known to produce good axial ratio, although achieving axial ratio bandwidth that covers the operational bandwidth is often challenging due to the fact that the mode phase difference varies strongly as a function of frequency. One approach to increasing the axial ratio bandwidth is to utilize thick substrates and low permittivity substrates, both of which lead to increased volume. We show in this section the key design parameter for the circularly polarized single feed patch, and then show the modifications to the design parameters that result in a multi-linear polarization design.

Although there are a number of ways to induce two closely spaced, orthogonal, resonant modes on a microstrip patch, we focus here on the "nearly square" approach in which the patch is offset relative to a square by a small area, ΔS, on one dimension. To achieve circular polarization at the band center, the value of ΔS is given by [2, 3]:

$$\Delta S/S = 1/Q_0 , \tag{1}$$

where Q_0 is the mode quality factor of each of the two fundamental patch modes. For circularly polarized antennas, Q_0 is selected to satisfy antenna efficiency requirements as well as impedance and axial ratio bandwidth requirements. As mentioned previously, of these three, the axial ratio bandwidth is usually the most demanding, and satisfying it often leads to thick substrates as well as overdesign in regard to efficiency and impedance bandwidth requirements.

B. Multi-Linear Single Feed Patch

As the ratio $\Delta S/S$ in the "nearly square" design increases beyond that required for circular polarization, the modes are move further apart and the eccentricity of the polarization ellipse increases; that is, the polarization becomes more linear. We define a parameter, sigma, as the ratio of the separation of the patch modes to the separation of the operational band:

$$\sigma = \frac{f_b - f_a}{b_w f_c} , \tag{2}$$

where f_b is the frequency of the higher frequency mode, f_a is the frequency of the lower frequency mode, b_w is the fractional operational bandwidth, and f_c is the center frequency. The relation of the patch perturbation $\Delta S/S$ and the parameter sigma is given by:

$$\frac{\Delta S}{S} = \frac{2\sigma b_w}{2+\sigma b_w} . \tag{3}$$

We select $Q_0 \approx 53$, which results in a mode 2:1 VSWR fractional bandwidth of approximately 0.013, less than half of the operational bandwidth of 0.028 for the EPCglobal UHF band. It is notable that this value of Q_0 is at least twice as large as is typically used in single feed circularly polarized patch designs, implying that the patch can be made substantially thinner. We further select sigma = 1.17, which results in $\Delta S/S = 0.033$. We find this combination of Q_0 and mode separation allows for a return loss better than 12 dB across the entire EPCglobal UHF band, and a lowest axial ratio of approximately 4.5dB, which occurs at the center band. The polarization characteristics at boresight can be estimated based on an expression for the relative mode excitation coefficients [2, 3]. Figure 1 show the resulting theoretical axial ratio and polarization ellipse tilt angle as the frequency varies from 902 MHz to 928 MHz for these values of sigma and Q_0 .

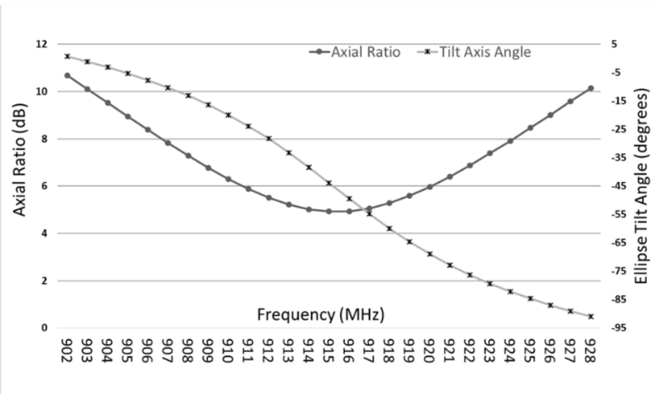

Figure 1. Axial ratio and tilt angle as a function of frequency.

The left axis in Fig. 1 shows the axial ratio is the lowest at the center frequency, where the mode amplitudes are equal. At either end of the band, the axial ratio is approximately 10. The right axis shows that the tilt angle covers an entire quadrant. At any fixed frequency within the 902-928MHz bandwidth, this antenna would be nearly linear and would result in high polarization loss when a linearly polarized tag is oriented orthogonally. However, owing to the FHSS protocol, the reader pseudo-randomly cycles through 50 channels across the operating band, and hence the antenna exhibits 50 different "nearly linear" (AR>4.5dB) polarizations over one quadrant. The next section presents the measured pattern and functional RFID test results.

C. Measured Results

A "nearly-square" microstrip patch is fabricated using the Q_0 and $\Delta S/S$ values specified above; i.e., 53 and 1.1, respectively, on a Rogers 3003 substrate with dimensions of $5.2 \times 5.2 \times 0.175''$. A ¼-wave impedance transformer is used to feed the patch at a diagonal and provide a 50 Ohm input impedance to the reader with a return loss ≤ 12 dB from 902-928MHz. Table 1 below shows the gain and axial ratio results for the realized reader antenna at the edges and center of the band.

Table 1. REALM-1 Antenna Gain and Axial Ratio.

Frequency	Peak Gain (dBi)	Axial Ratio (dB)
902	6.6	10.4
915	6.4	4.5
928	7.3	7.8

D. Functional Test Results

To compare RFID performance with a circularly polarized antenna, a second antenna is built with the same Rogers 3003 substrate. It is fed by a quadrature hybrid with dual probe feed to obtain circular polarization. The loss of the quadrature hybrid assembly is 0.5 dB. Each antenna is connected to an Impinj Speedway R420 reader, and the power is successively reduced until the tag cannot be read. Two types of tags are used, the Alien squiggle mounted against a Styrofoam background, and the Metalcraft Universal Mini mounted on an aluminum plate. Four tags of each type are presented at 4 orientations. The results are shown in Table 2 below, where the threshold power corresponding to the CP antenna is subtracted from that of the multi-linear antenna, so that negative values imply tag reads at lower power by the multi-linear antenna.

Table 2. Comparison Test: ML Threshold – CP Threshold (dB).

Tag	0°	90°	45°	135°
Squiggle	-3	-2	0.2	-1.6
Metalcraft	0	-2.8	1	-2.2

III. Summary

The multi-linear patch reader antenna is shown to exhibit several highly desirable features for RFID applications that employ a frequency hopping protocol. First, it is found to provide improved polarization diversity compared to a CP reader antenna for RFID links with linearly polarized tags. This is of significance because the reader antenna gain and transmit power are typically limited by regional regulations, and the tag performance is generally limited by size. Thus, reducing the polarization loss of the link can provide significant performance enhancement in RFID links, resulting in longer range and/or higher read accuracy. Second, the implementation of the multi-linear antenna necessarily requires narrowband patch modes at wider separation. This permits options to reduce the size of patch reader antennas, both in lateral dimensions, owing to use of higher substrate permittivities, and substrate thickness.

References

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